Muon radiography of Vesuvius

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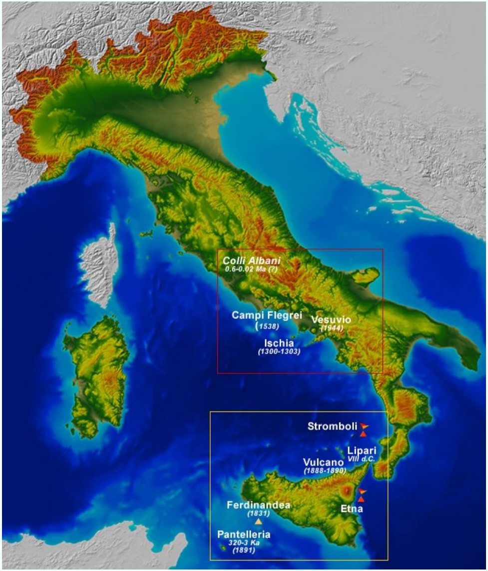
Summary

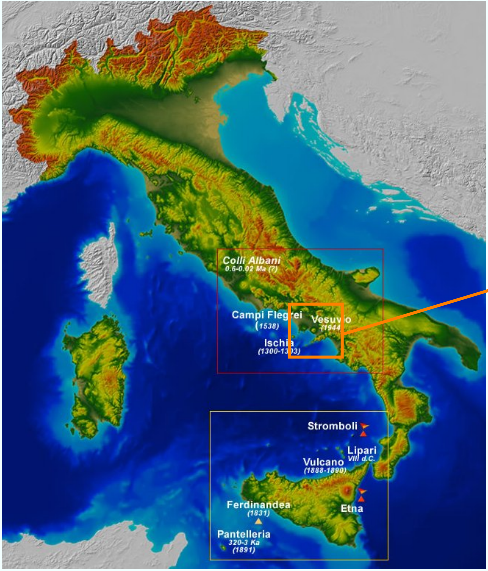
1. Active volcanoes in Italy
2. Knowledge of the internal structure of Vesuvius
3. Muon radiography of volcanoes
4. Conclusion

Active volcanoes in Italy and Vesuvius

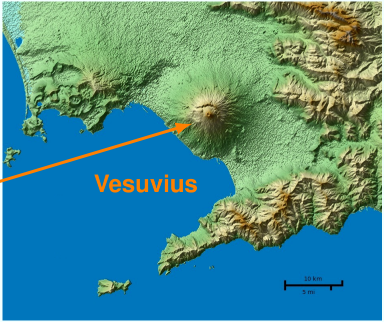


The principal active volcanoes (10)

Active volcanoes in Italy and Vesuvius



The principal active volcanoes (10)



- **Last eruption occurred in 1944**
- **Now the conduit is closed**
- **Monitored 24/24**

Last eruption of Vesuvius (1944)

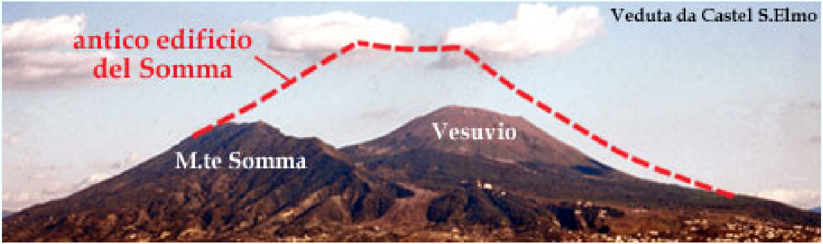
Vesuvius is a high risk volcano

More than 550,000 people live in the “Red Zone” of Vesuvius

Vesuvius today

A reconstruction of Mount Somma

- Vesuvius is an active volcano (now quiescent), 1280 m high
- Vesuvius was grown in the caldera of an older, larger volcano (Mt. Somma)



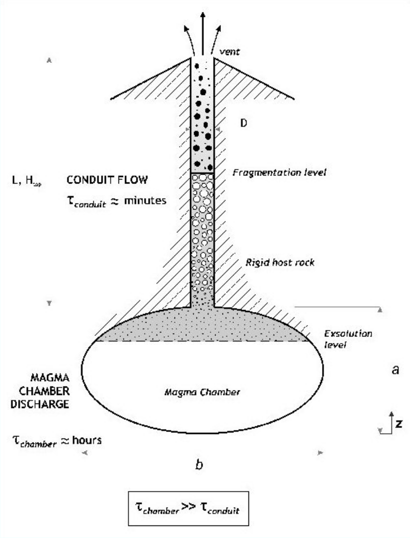
Picture of Vesuvius before Pompei eruption (79 AD)

Fresco from Pompei, Casa del Centenario (now at Napoli Archaeological Museum)

Vesuvius was thought to be “a mountain”

People had not realized the danger

Simplified scheme of a volcano



(from Martí et al., 2000)

The eruption dynamics depends on:

- Gas content
- **Dimension and shape of the conduit**
- Magma chemical composition

Example of internal volcanic conduits (dikes)

Emerged dyke at Crater Lake

Emerged dyke at Etna

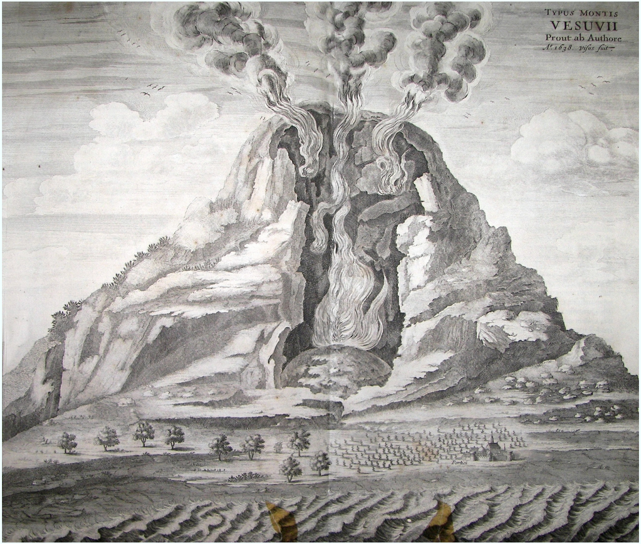
Knowledge of the internal structure of Vesuvius

What we know about the volcano structure?

- Previous knowledge (Kircher, 1638)
- Active seismic tomography (TOMOVES-1996/MAREVES-1997)
- Passive seismic tomography (based on natural earthquakes)
- Gravimetric field inversion
- Direct observations of the interior of the crater
- Muon radiography

Knowledge of the internal structure of Vesuvius

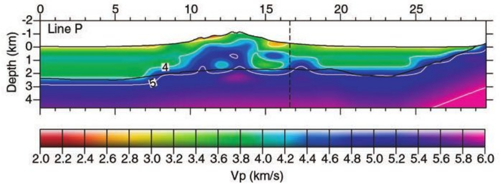
The first studies of Kircher in 1638



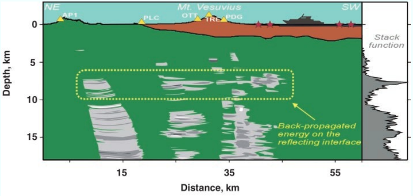
Knowledge of the internal structure of Vesuvius

Seismic active tomography (TOMOVES-1996 and MAREVES-1997 experiments)

- Active seismic tomography
- Spatial resolution $\approx 0.5 - 1$ km



(modified from Di Stefano and Chiarabba, JGR, 2002)

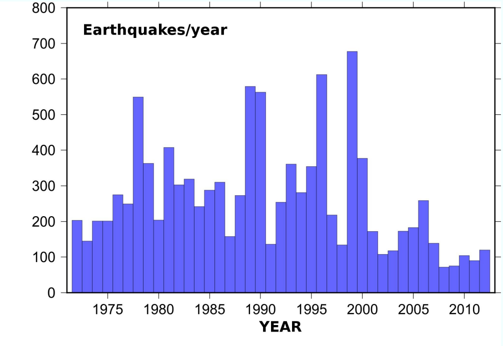


(from Auger et al., Science, 2001)

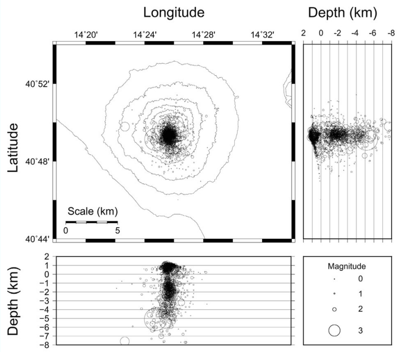
The internal structure of Vesuvius

Study of the natural seismicity

Vesuvius earthquakes/year 1971-2012



Earthquakes locations 1999-2012

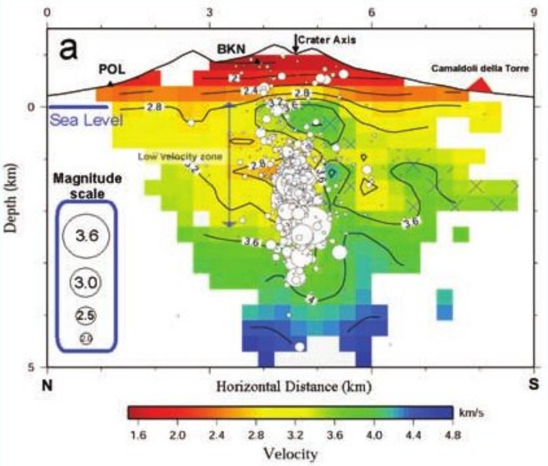


(from D'Auria et al., Annals of Geophysics, 2013)

- Typical magnitude $M_L < 2.0$
- Largest earthquake $M_L = 3.6$

The internal structure of Vesuvius

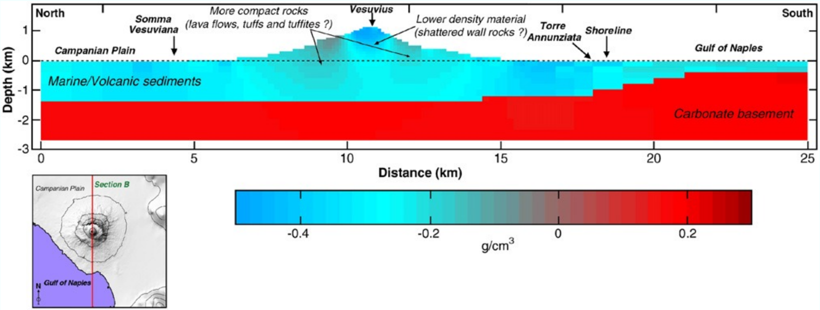
High resolution passive seismic tomography (300-500 m)



(from Scarpa et al., GRL, 2002)

The internal structure of Vesuvius

Gravimetric field inversion (spatial resolution ≈ 250-500 m)

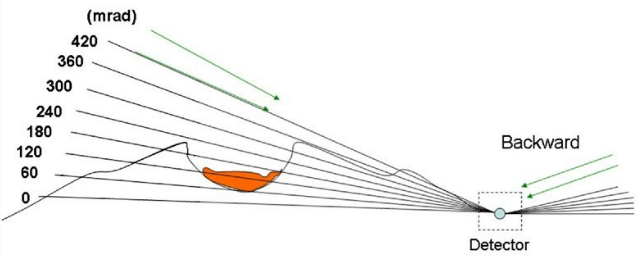


(from Cella et al., JVGR, 2007)

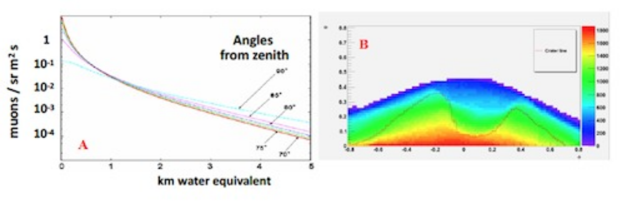
Muon radiography of a volcano

The principle

(from Tanaka et al., 2007b)

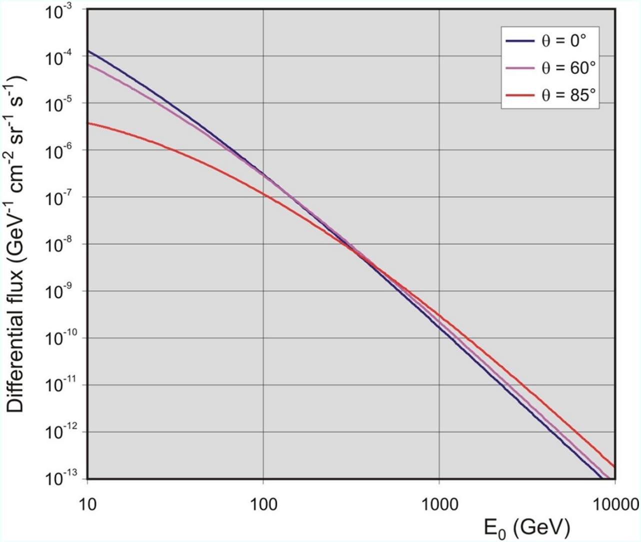


Muon absorption at Vesuvius



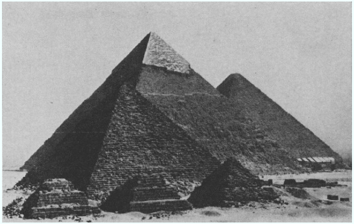
Muon flux

Typical muon flux at different zenith angles

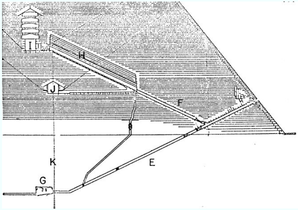


The Pyramids of Giza

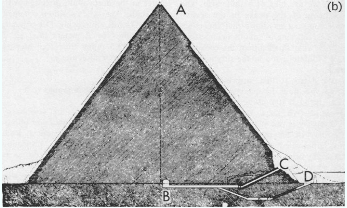
Is there a chamber inside the Chephren pyramid?



Micerino - Chephren - Cheope



Cheope

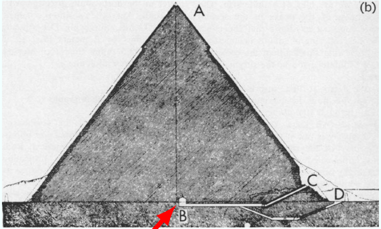


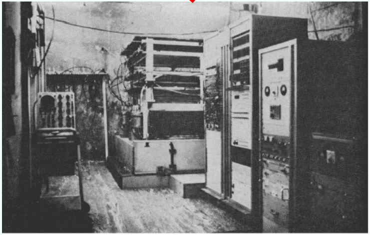
Chephren

The experiment of Luis Alvarez in 1970

Radiography of the Chephren pyramid with cosmic muons

Luis Alvarez
Nobel Prize (Physics)
1911-1988





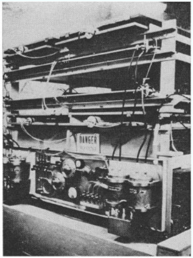
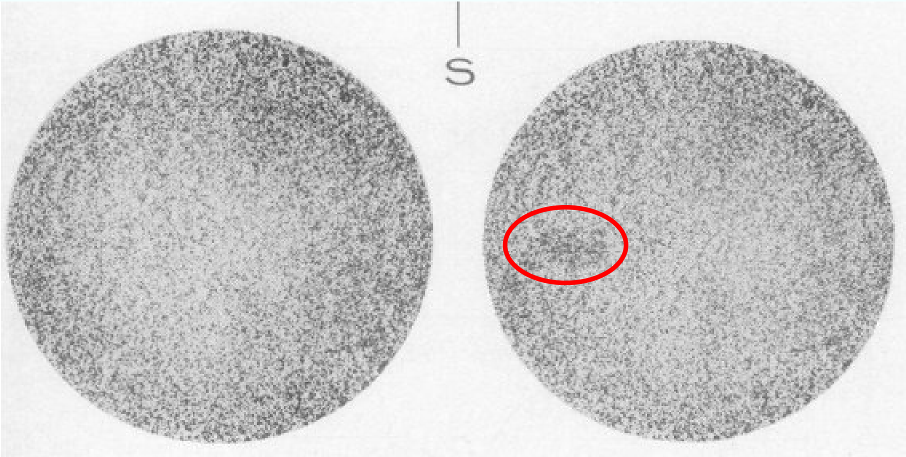


Fig. 6 (left). The equipment in place in the Belzoni Chamber under the pyramid.
Fig. 7 (right). The detection apparatus containing the spark chambers.

(From Alvarez et al., 1970)

Result of the Luis Alvarez experiment

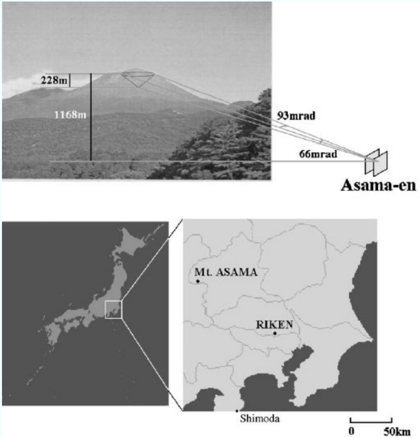


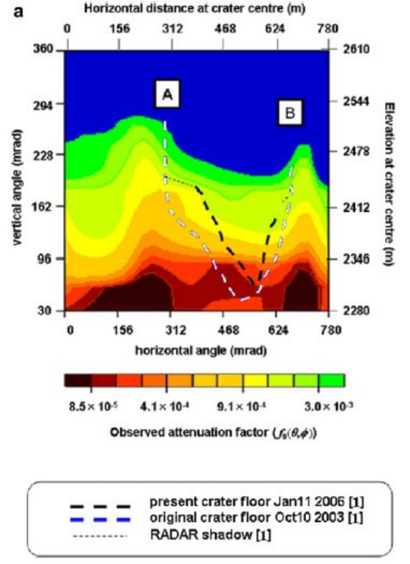
Observation **Simulation with the chamber**

(From Alvarez et al., 1970)

Muon radiography of Mount Asama, Japan

With nuclear emulsions,
since 2003

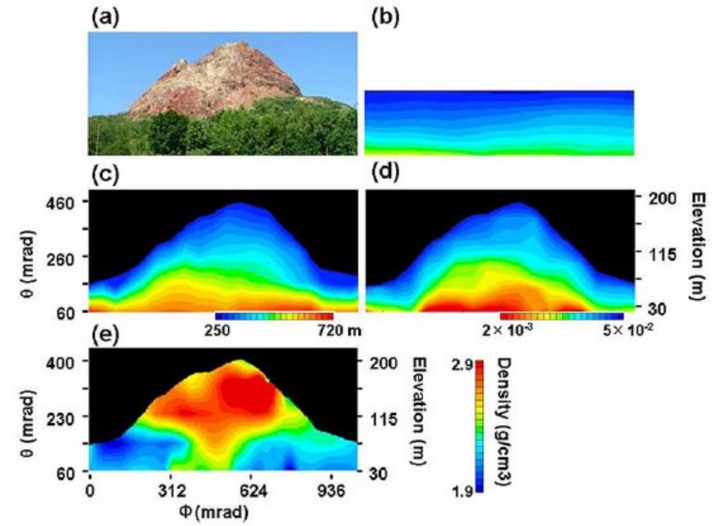




(Tanaka et al., 2003, 2007b)

Muon radiography of Usu volcano, Japan

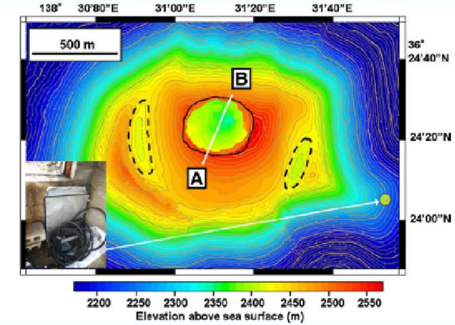
The Showa-Shinzan lava dome



(From Tanaka et al., 2007a)

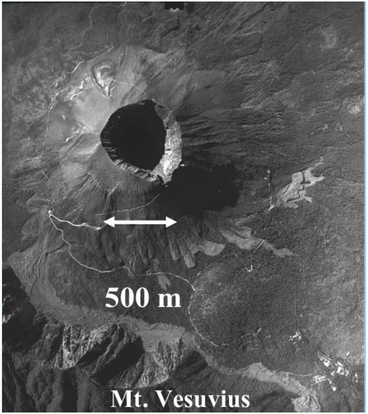
Muon radiography of Vesuvius

Mt. Asama (2650m) and Vesuvius (1280m) are similar

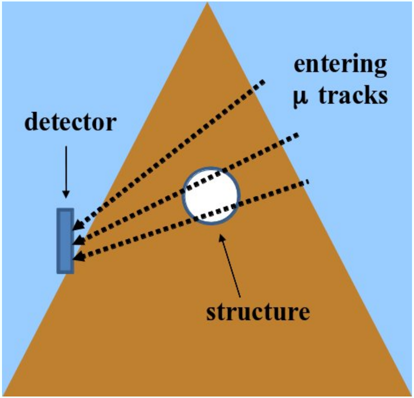


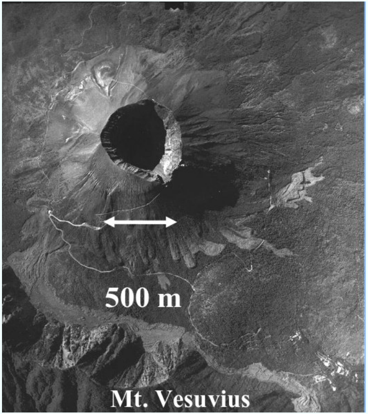
Mt. Asama

(from Tanaka et al., 2007b)



Expected spatial resolution



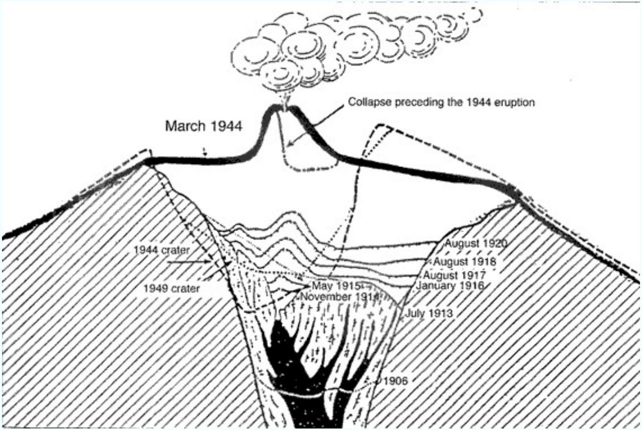


Angular resolution: 10mrad
Spatial resolution (@1km): 10m

Recent evolution of the Vesuvius crater

What we expect from muon radiography

The Vesuvius crater between 1906 and 1944



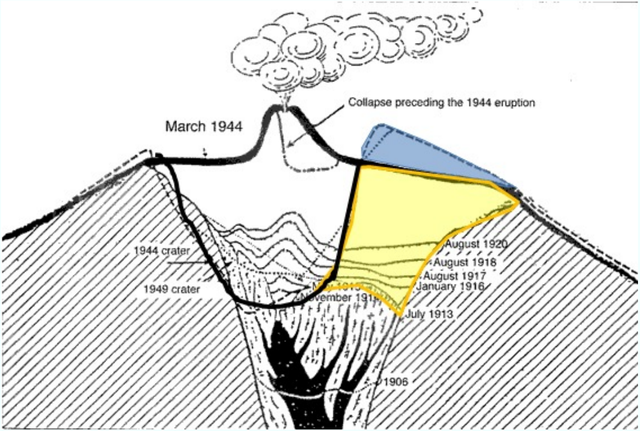
(from Imbò, 1949)

Vesuvius crater in 1944

Recent evolution of the Vesuvius crater

What we expect from muon radiography

The Vesuvius crater between 1906 and 1944



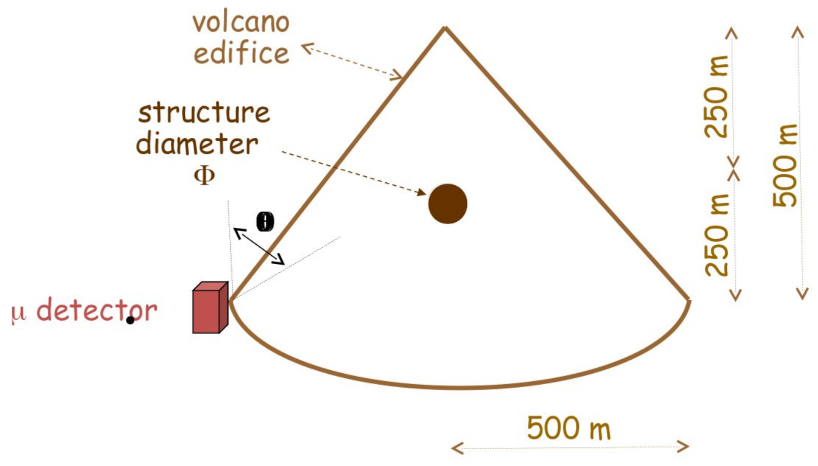
(from Imbò, 1949)

Vesuvius crater in 1944

Vesuvius crater today

Estimate of μ rate and sensitivity

Geometrical model



Estimate of μ rate and sensitivity

Rates and required detector area x time

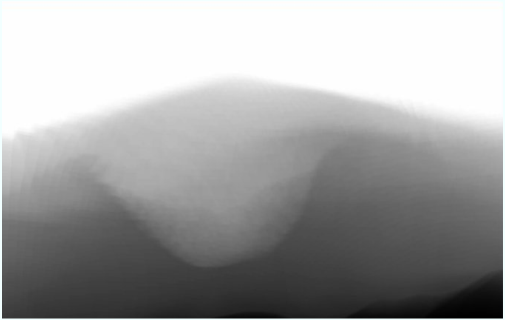
Φ of structure [m]	20 $\rho = 0$	50 $\Delta\rho/\rho_0 = 0.1$
Rate N through structure [m^{-2} day^{-1}] (ρ_0 = 2.2 g/cm^3, $E_\mu > 0.5$ GeV)	2.5	16
ΔN/N by structure	0.09	0.02
Events for 3σ detection of structure	1,150	20,000
Detector area $\times$ time [m^2 month]	**15**	**40**

MURAVES detector: 4 m^2.

First experiments at Vesuvius
The MU-RAY project

Detector location (MU-RAY)

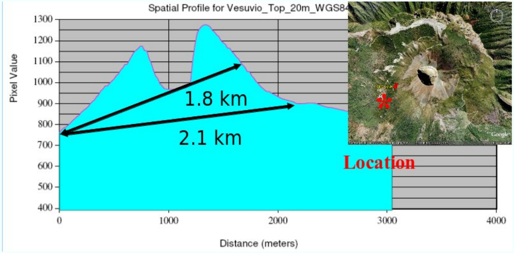
Map of the thickness



(from Macedonio and Martini, 2010)

The MU-RAY project

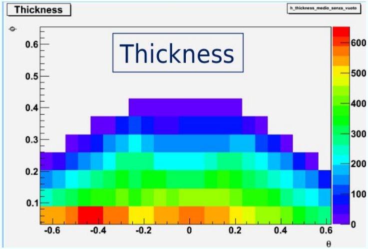
- Japanese detector tested at Vesuvius
- Two parallel planes (distance 1.2m)
- Each plane has 12 plastic scintillators (100x7x3cm), coupled with photomultipliers (52mm diameter)



The MU-RAY experiment at Vesuvius

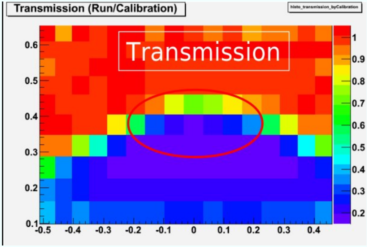
Mounting the Japanes detector, 2009-2010

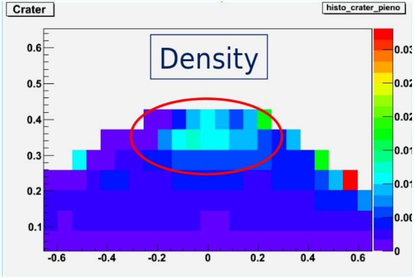
Preliminary results at Vesuvius



Vesuvius cone “seen” from the detector

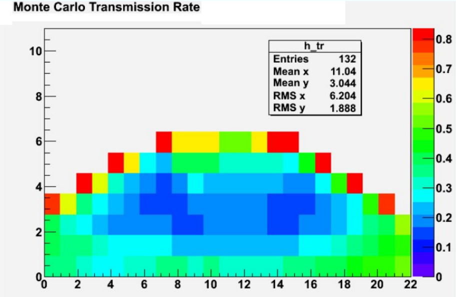
$$\rho \propto \frac{\text{Absorbtion}}{\text{Rock thickness}}$$



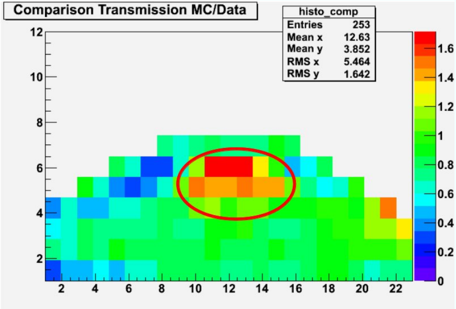


Comparison with Monte Carlo simulations

Monte Carlo Transmission rate



Comparison of Monte Carlo and data



A step forward: The MURAVES Project

Funded by the Italian MIUR (start in January 2015)

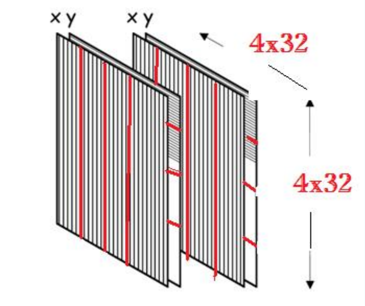
Objectives

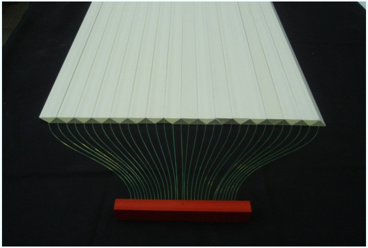
- To develop a **synergy between geophysics and particle physics**
- Achieve an **integrated model of the Vesuvius' structure** based on muon radiography, gravimetric and seismological data

Method

- Build of **new telescopes** for volcano radiography using cosmic muons with better resolution and background suppression than previous experiments
- Development of an **innovative model** for the integration of data from muon radiography, gravimetry and seismology

The new telescope





- Area 2x2 m^2
- Triangular shape scintillators (Fermilab)
- Scint. light collected by WLS one-side mirrored fiber (BCF92 fast response fibers from Bicron)
- Dedicated 32 fibers optical connector
- Dedicated SiPM from FBK-IRST
- Dedicated hybrid hosting 32 SiPMs
- SiPM temperature control by Peltier cells
- SPIROC 0 ASIC FEE (from Orsay group)
- Dedicated read-out and acquisition board
- Measurement of the muons time of flight

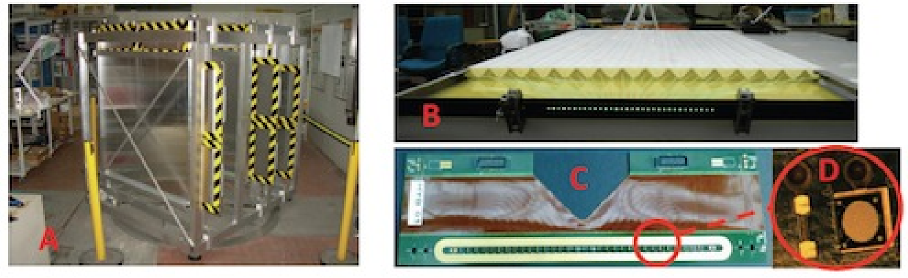
Expected performances:

- $\approx$3 mm space resolution (by measurement of charge sharing between two adjacent strips)
- $\approx$1 ns time resolution
- O(10) W power consumption

The new telescope

INFN, INGV, Universities of Napoli and Florence

- The MURAY2/MURAVES prototype is under test



Conclusion

- The investigation of the internal structure of volcanoes using cosmic muons is a challenge
- Promising results of muon radiography are obtained on Japanes volcanoes
- Experiments in Europe were performed on Vesuvius, Etna, Stromboli (Italy) and Puis de Dome (France)
- The integration between seismic, gravimetric and muon radiography data (MURAVES Project) is completely innovative

References

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